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The experience of Addcar in highwall mining operations

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THE EXPERIENCE OF ADDCAR IN HIGHWALL MINING OPERATIONS

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ABSTRACT: Within coming years, Highwall mining (HWM) as a technology, will be more frequently considered as a means to optimise resource recovery within a particular mining context and assessment of the risks/benefits associated with such a technology need to be fully addressed by those undertaking the assessment. The Addcar technology has been in the forefront of innovation and technological enhancements since its introduction in 1990. The experiences of the Addcar team, in Australia and the USA is that the requirements for successful utilisation of the system or its counterparts, the range of applications and the comparative capability of the relevant systems are often not fully understood and as a consequence opportunities are lost or projects commenced with unrealistic expectations. Through the use of explanatory examples and references, the authors seek to highlight those areas of critical nature that require specific focus when assessing the potential use of HWM technology and the range of applications such technology can be utilised in.

INTRODUCTION

Highwall mining (HWM) is a hybrid mining arrangement whereby underground mining methods are used in a surface environment using a combination of underground, surface and specialised equipment. Many in the Australian industry have broad views as to what constitutes HWM and relate past experiences and apply particular biases to strategic planning decisions that in some cases are technically outmoded and commercially incorrect.

The Addcar system has been operating the longest of any system (since 1990) and has mined more tonnes (approx. 120Mt) across a broader range of conditions and therefore is a suitable HWM system for benchmarking performance, establishment needs and resource assessment.

Discussion herein is therefore centred on Addcar experiences and learnings and further information on the specific nature of the Addcar and other HWM systems can be sought from respective suppliers.

This paper seeks to undertake comparative analysis between two distinct Eras (refer section 2 below) of HWM in Australia and notes operational differences between the USA and Australia where appropriate.

The intention herein is that potential users of HWM technologies can make educated judgements regarding recovery and production rates when assessing the full potential of any resource.

HISTORY

The Addcar system was first operated at the Boomer Mine in Fayette County, West Virginia in 1990 and since then has mined in excess of 120 million tonnes internationally with in excess of 21 million tonnes being mined in Australia. Other HWM variants have been developed but have not captured the market spread or achieved the consistency of results over such a wide range of operational conditions over the same time period.

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Figure 1: The first Addcar system in 1990 and current Launch vehicle configuration

The Addcar system was initially introduced into Australia in 1995 and in 2014, the current owners purchased Addcar from Arch Coal and reintroduced the technology into Australia after a ten year hiatus. This period of inaction in Australia has resulted into two distinct timeframes of HWM operation nominated in this paper as:

- **Era 1:** 1995 to 2003, and
- **Era 2:** 2014 to present.

Consequential improvements to Guidance Technology, Resource Assessment and Geotechnical Design need to be applied to factual assessments of potential mining sites rather than reliance on various past outcomes with differing technologies and outdated design assumptions. In addition, by operating in differing international locales Addcar are in a unique position to relay information on factors affecting costs, efficiency and productivity that should be considerations for current review of operations and competitive analysis in Australia.

A BRIEF COMPARISON OF HWM SYSTEMS

The following table is for the purposes of illustrating the relevant potential differences between available technologies and is believed to be factual at the time of writing, each proponent should confirm current trends and system limitations at the time of assessment.

Table 1: Broad comparison of Key Operational Factors between available system technologies

Key Operational Factor	Addcar CM Based with conveyor coal clearance	Other CM Based Systems Auger based coal clearance	Auger Based Systems Auger coal cutting and coal clearance
Depth Capability	Subject to dip – 500 meters system capability, car conveyors are individually powered	Nominally 300 meters – car augers are powered from the surface	Nominally 100 meters
Dip Capability	Subject to dip – in excess of 15 degrees, have mined in excess of 20 degrees (*Westmoreland Kemmerer Mine in Wyoming – 2018*)	Limited to 8 degrees	Limited to 8 degrees
Fines Generation	Typical underground fines generation using CM	Use of auger conveyor system generates higher proportion of fines than conveyor based coal clearance	Use of auger coal cutting plus auger coal clearance creates highest proportion of fines.
Guidance	3rd generation INS and 5th generation guidance system	Nil	Nil

ASSESSMENT OF POTENTIAL

It is generally the absence of key aspects as outlined below that result in poor assessment and incorrect decision making regarding the go ahead or otherwise for HWM.

Regional and local geological characteristics of the site must be determined in order to establish a base geological/geotechnical model leading to a Geotechnical Design for the mining layout.

Key data inputs include:

- Geological setting
  - coal measures features
  - regional folding and faulting
  - stress regime, igneous activity etc
- Sedimentology and Strata Conditions
  - nature and characteristics of overlying and underlying strata, lateral variability
  - Presence of water, coal seam aquifers, etc.
  - Floor trafficability
  - Gas permeability and desorption
- Structural features and Highwall Mapping
  - faults, jointing, seam rolls, measurements of orientation, dip etc.
- Seam characteristics
  - rank, brightness, cleating, shearing, dirt bands etc.
  - proposed seam cutting sections

Projects are justified on the basis of the resource recovered and the production rate, nothing impacts on both performance KPIs like "highwall surprises" and whilst most issues can be accommodated through appropriate management, it is impossible to meet targets when confronted with a feature that could be mapped and highlighted at planning/ assessment stages.

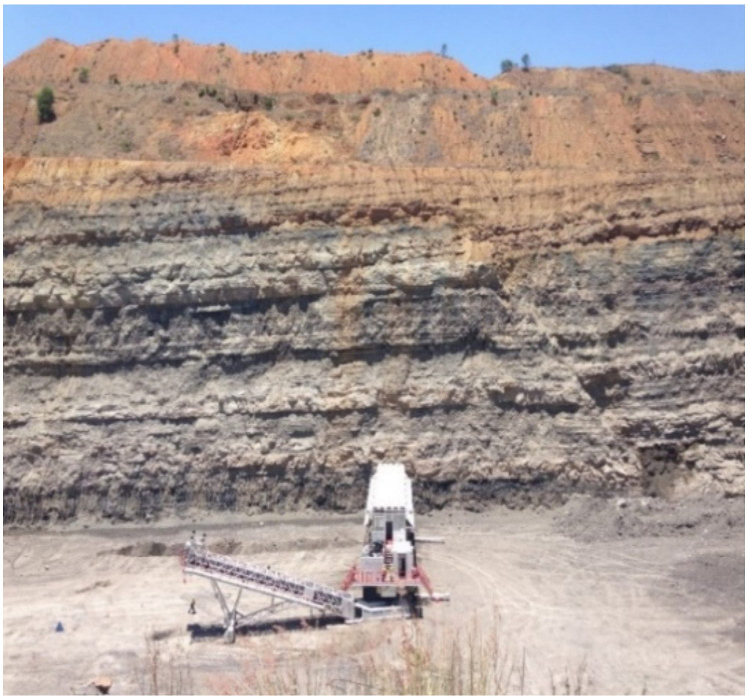

Figure 2: An actual Highwall "Surprise"

HWM HISTORICAL KEY DATA

It is beneficial to have some understanding of the potential performance of HWM and whilst extremely difficult to readily transfer data from the USA to Australia, there is some useful comparative information that can be reviewed and assessed within the context of potential Australian projects.

Productivity

Table 2: Productivity (all US mines) by mining method - 2009

Mining Method/Locale	Tons per Employee Hr
Western Surface Mines	19.9
ADDCAR	10.0
Longwall Mines	4.3
Eastern Surface Mines	3.7
Non-Longwall Underground Mines	2.6

HWM productivity is a function of process, seam height and bench condition but nominally, output per man employed will be lower in Australia than the USA for comparative conditions due to OHS and IR requirements.

Sizing

The HWM system utilises a continuous miner to extract the coal and proponents should be aware that as a consequence the fines generation will be greater than that resulting from mining the same seam by open cut means and will be slightly less than conventional underground mining of the same seam due to the reduced shatter points in the coal clearance system.

The auger coal clearance systems result in an approximate increase of 20% in fines generation over the conveyor based coal clearance systems.

> *When assessing the introduction of HWM, consideration should be given to the CHPP processing requirements and fines circuit throughput capacity.*

Safety

By far, statistically the biggest fatality safety risk to employees associated with HWM is Rock Falls from the highwall.

Other obvious risks relating to machine entrapment evolve due to inappropriate geotechnical design, non-adherence to the design or changed conditions in entries resulting in amendment to the design. The employee risk associated with such circumstance again relates to the highwall as any catastrophic subsidence event may lead to highwall instability.

Statistically, the most frequent cause of injury relates to machinery interaction.

Generally, safety statistics for HWM are equivalent or less than those achieved in surface mining.

Procedures, management plans, inspection and reporting regimes are required to address the exposures as noted and recent refinements to Permit to Mine (PTM), Entry Design reviews, highwall geotechnical inspection and monitoring, FOPs protection on equipment, use of safety berms have been instigated into daily and shiftly mining practice.

> *Fundamental to the success of any HWM operation and the safety of the employees involved is the Geotechnical Design. The design is only as good as the data available*

and whilst the monitoring of conditions encountered are vital to continued design refinement, the critical phase of design is at the assessment stage prior to commitment.

Resource recovery

It is critical that the assessment phase of HWM potential studies utilises realistic resource recovery parameters.

A realistic boundary condition for entry depth consideration is actual depth which nominally will be 80% of planned depth so that for a defined resource block of 400 metres depth, the average achieved depth will be 320 metres.

Resource recovery is ultimately, primarily a function of seam height and depth of cover with additional analysis based on localised conditions being required. For thin seams with low height highwalls, 60% (by plan area) or higher can be achieved whereas for thicker seams and higher highwalls (depth of cover) the figure can be below 40%.

In thicker seams multiple passes can be undertaken but w/h ratios and rib stability issues eventuate and there is an economic consideration based on resultant coal recovery and required entry geometry.

A conservative approach to resource recovery is appropriate but front end data capture and application remains the most reliable means of reliable entry design and therefore economic assessment.

MINE PREPARATION (HIGHWALL, DRAINAGE, BENCH, SERVICES)

Whilst the HWM system can mine varying dips, the Launch Vehicle (or its counterpart) requires the bench area to be prepared to enable efficient establishment, coal clearance and stockpiling and working area to allow traffic management and component handling.

Pit layout requirements:

- 5 degree cross-grade and dip maximums on bench floor
- 50 metre minimum pit width
- Drainage sump
- Stable highwall and low-wall
- Stand-off 8 metres

Figure 3: Prepared Operating Bench with Berm and Drainage in Place

Appropriate effort into sump design, low wall and highwall water drainage, berm construction, utility supply, traffic management and bench development leads to productivity as opposed to continued delays and lost coal if focus is not placed on this facet of the HWM operation

GUIDANCE

Highwall mining (with drives as long as 500m) is an unmanned extraction system and all key data should be captured and relayed in an interpretive format to the operator on the surface.

The ADDCAR highwall Mining Guidance System (MGS) has been developed and proven in the field and since its introduction in 1996, there has not been a single incidence of mine structural failure or equipment entrapment attributable to navigational issues.

The primary purpose of the guidance system is to mine to the plan, leave a safe mine structure and protect machinery in the drive from localised strata failure by;

- Maintaining pillar width and prevent intersecting plunges (primary purpose)
- Maintaining a consistent floor cut horizon to control spillage and prevent miner and cars becoming bogged
- Maintaining roof/floor beams where required to prevent localised roof collapse and equipment damage or entrapment

The guidance system enables greater coal recovery and productivity as the factors of safety on the geotechnical design can be reduced. Current NSW guidelines requires an increased factor of safety for systems without guidance fitted.

ADDCAR's Guidance System is the subject of ongoing innovation and enhancement and incorporates a number of specialized and integrated Proprietary components and software:

- A customised Inertial Navigation System (INS) which uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate orientation of the miner (azimuth, pitch and roll). Addcar has the only current United States Department of Defence approval to use this technology.
- Odocam, which measures movement in or out along the drive, is a bespoke system that uses a computer, video camera and markers (effectively a ruler) to continuously determine and provide the precise position of the equipment in the drive.
- Gamma sensors positioned on the miner to sense the depth of coal in the roof or floor of a drive. These are bespoke crystal sensors which detect radiation given out by mineral materials (rock). They assist in controlling boom height / cutting within the desired constraints. *Successful use of the roof gammas is very much dependent on seam conditions and current preference is to utilise the floor gammas (more consistent over wider range f conditions) and use pre-set height limiters.*
- Vertical Reference Unit (Inclinometer) on the miner boom is lower performing INS unit which provides suitably accurate indication of the miner boom position.
- The guidance computer and operator interface (called MK4), is a bespoke solution which interfaces with the above sensors and determines and directs the operator via a graphical interface in the control cab.

Figure 4: Operator's Screen

The guidance system interfaces with the PLC control system of the launch and so enables interactions for automated control and control interventions under specific events.

The guidance system also maintains a history log of all drives for review and reference. This data is post processed to provide hole reports and profiles.

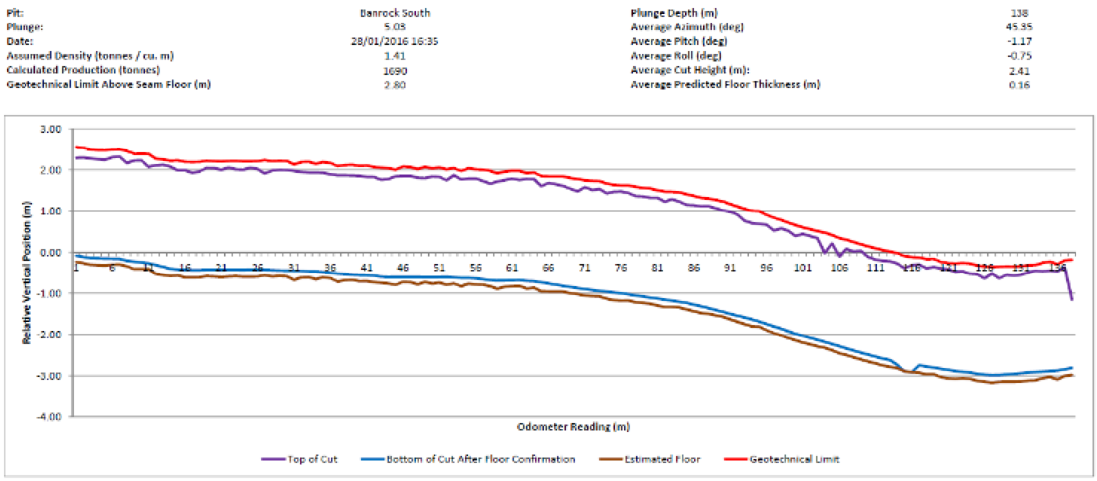

Figure 5: Typical Addcar Hole Report

It should be noted the guidance system while suitably accurate is not a survey tool and does not provide the levels of accuracy typically seen or expected of surveys.

GAS MANAGEMENT

The legislation both in NSW and QLD is not specific to the spectrum of conditions as encountered in a HWM entry and the reintroduction of HWM brought with it a need to address historical misconceptions and to incorporate technological advancements with respect to gas management within entries.

Unlike UG mining where it is basically methane mixed with air and control is achieved by diluting the methane with air, there are multiple dimensions to flammability control when undertaking HWM. Manipulation of the oxygen concentration as well as the methane concentration can be achieved through the introduction of inert gas (nitrogen) and extraction rates.

Broad outcomes of the Investigation included:

- The effects of Nitrogen (N) inertisation and consequential low quantity of ventilation gas meant
    - At full production rates ~30% of gas goes into filling the void (based on peak coal production. Addcars would reduce this void slightly
    - Air velocity is in the order of 15 to 20cm/second (0.015m/s)
    - This means that gas make at the face might not show up on outbye sensors for a considerable period of time therefore the best indication for the explosibility of the environment is at the miner.
- HWM Methane Sources were broadly categorised into three main areas:

1. **Cutter head** (accounts for 80 to 90% of emissions)
    - Will be proportional to the rate of extraction
    - Will increase if product size is reduced
    - Related to gas content and desorption rate
    - Pre-existing entries may reduce emissions, *needs to be assessed by site*
2. **Conveyor**
    - Will be proportional to the rate of extraction
    - Increases with smaller product size
    - Will be proportional to the time coal spends on conveyor (length and speed)
    - Related to gas content and desorption rate
    - Pre-existing entries will reduce emissions
3. **Rib / roof / floor and face** emissions
    - Will be proportional to the rate of advance
    - Will be proportional to area exposed
    - Related to gas content and desorption rate
    - More permeable coal will increase emissions
    - Pre-existing entries will reduce emissions

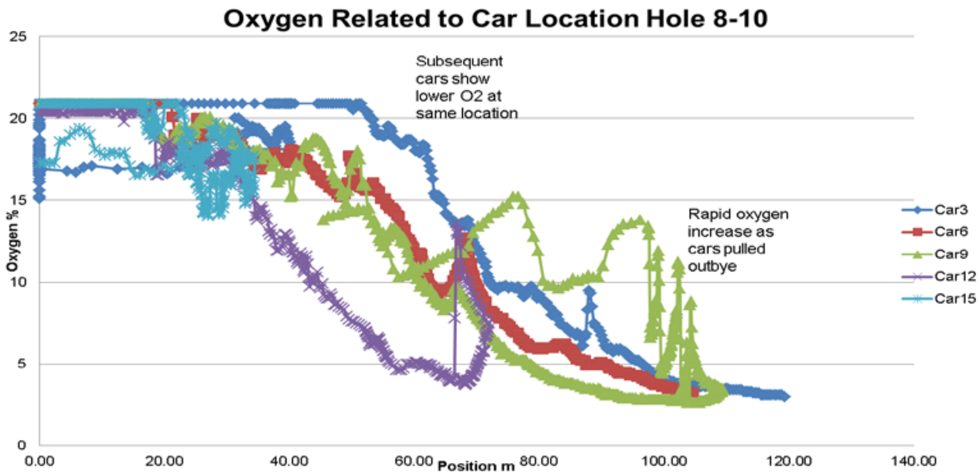

Figure 6: Graphical representation of In-Field O monitoring results

For the purposes of risk categorisation and monitoring, the three Zones were defined based on nominal entry length.

- **Zone 1: At face (If face >100m from portal)**

  - o Oxygen (O) (3%) low as N discharge is at face
  - o Methane (CH4) could be high right at cutter head if mixing not complete
  - o no realistic probability of explosion

  Outbye (approx. 100m from portal)

  - o O still low (3 to 5%)
  - o CH4 could be significantly higher than at cutter head due to rib and conveyor emission being added to cutting emissions (dependent upon length of ribs and conveyor)
  - o Still no realistic probability of explosion

- **Zone 2: Outbye (80m down to 20m from portal)**
  - o Critical Zone – defined as the Transition Zone
  - o O probably 12 to 18%
  - o CH4 could be high (rare circumstance) due to rib and conveyor emission being added to cutting emissions but is likely to start declining due to dilution with air
  - o Potential for explosive mixture in this area if controls not applied

- **Zone 3: Portal (20m down to portal)**
  - o O could be still 18 to 20%
  - o CH4 rapidly declining due to dilution with air
  - o Potential for explosive mixture in this area is rapidly declining due to rapid dilution of CH4

There is no clear legislation or guidelines for inertised highwall mining gas management but in conjunction with QLD Inspectorate the following trigger map (based on Coward's Triangle) has been used to set alarm and trip levels when operating the Addcar HWM.

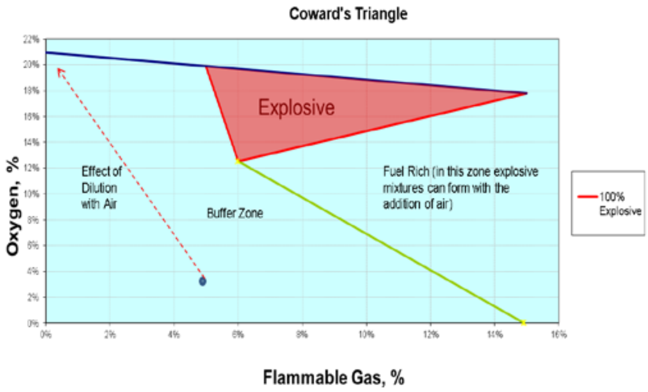

Figure 7: Cowards triangle and operational buffer zones – applied to each monitoring zone

Trip levels are then set at a point where flammable gas is <50% of ignitable or fuel rich line when working in a low oxygen environment and are achieved by:

- Monitoring environment at the CM, either side of Transition zones and on LV deck
- Commence mining utilising a methane trip of 2.5% when oxygen >5%
- Automatically transitions when oxygen <5% to trip when methane >5.5%
- This system is not reliant on operator interaction.

Gas management in HWM entries in Australia is achieved through monitoring, control and injection by using the combination of the introduction of inert gas, the speed of extraction and the multi-point sensing throughout the entry.

GEOTECHNICAL ANALYSIS AND ENTRY DESIGN

Historically, there are quite a number of research papers that analyse and discuss highwall failures and HWM panel failures and this paper does not seek to elaborate beyond experiential outcomes and collaborative undertakings with nominated industry specialists.

A brief summary of historical failures in the **Era 1** period in Australia highlights the impact of:

- **HWM Guidance** – a number of pillar failures, in Australia and the USA, occurred in the 1990s due to the narrowing of the pillar between entries as a consequence of the continuous miner tracking away from the entry alignment. Since the introduction (1996) and refinement (ongoing) of the HWM Guidance system, there has not been an occurrence of pillar failure due to entry misalignment with the Addcar system.
- **Geometrical Pillar Design** – a reliance on FoS as the principle design parameter and the exclusion of Barrier Pillars led to a number of “Cascading Pillar” failures. The use of Barrier Pillars in Panel Designs is now common practice.
- **Time Based Geometrical Decay** – insufficient allowance for the time based decay of entry geometry, especially in the presence of water and clays in surrounding strata contributed to post mining failures. Remains a critical issue in designing stability of pillars.

Current issues based on experiences (good and bad) since 2014 (**Era 2**) highlights the requirement to assess any potential HWM site against the full backdrop of proposed Entry Geometry and strata/ground/highwall conditions both at the time of mining and post mining. A common problem as encountered both in the USA and Australia is a simplistic over-reliance on geometrical determinations for entries based on singular application of accepted industry formulas.

Generally, data relating to strata, water, structure is poor or almost non-existent and as a consequence adverse outcomes can eventuate that are not HWM related but rather as a consequence of inadequate design due to the non-inclusion of localised conditions in any applied entry design.

Analysis of historical Australian highwall mining operations have highlighted the requirement to complete designs on the basis of pillar w/h ratios as well as FoS ratios, noting that localised geotechnical anomalies influence the w/h ratio significantly and must be accommodated in any conservative design.

Addcar have worked with various parties and currently undertake design based on an Upper Design Limit (UDL) with a minimum Factor of Safety (FoS) of 1.6 (as per US guidelines) and a minimum Width to Height ratio (w/h) of 1.2 based on the likelihood that pillars with a w/h ratio of <1 are particularly susceptible to catastrophic failure and the consequent need for a 20% buffer to allow for any significant structural defects that may be present in the coal, potential misalignment in the drives and/or unplanned increases in the cut height.

A Lower Design Limit (LDL) is based on a minimum FoS of 1.28, which is no more than 20% less than the recommended minimum FoS of 1.6, and as per the upper limit of the failed cases shown in the database, a minimum w/h ratio of 1.

References to geotechnical design issues in **Era 2** are limited to those as experienced by the author(s). Four examples are referenced due to the specific outcomes and relevant contributory factors which are noted with advisory pointers for addressing in resource assessment stage and subsequent definition of operational requirements.

Example 1:

Outcome:	Slippage failure of highwall face.
Immediate Cause:	Cascading pillar failure
Contributing Factors:	Deterioration of entry geometry over time due to the influence of water in strata and overlaying clays
Remedial Action:	Altered entry/panel design to accommodate the eventual change in entry dimensions
Resource Assessment:	*A full assessment of highwall structure and surcharge plus strata and water ingress and potential for impact on entry geometry and probable deterioration phase*.

Figure 8: Time based decay of entry due to ingression of water

Example 2:

Outcome:	Highwall debris fall, striking light vehicle.
Immediate Cause:	"Ski jump" in highwall face deflected debris away from vertical trajectory and into light vehicle.
Contributing Factors:	Failure to maintain continuity of berms in bench
Remedial Action:	Berm Construction
Resource Assessment:	*Most (if not all) highwalls will not be prepared with HWM in mind and therefore there is an increased probability of highwall debris falling. The need for a means to catch deflected debris must be incorporated into planning and mining permits. Berms can effectively be used to control rock fall hazards by creating a catch basin and providing an effective barrier to keep personnel out of the operational area; but they must be properly sized, located and maintained*.

Figure 9: Incident highwall – no berms and Ski Jump

Example 3:

Outcome:	Buried CM
Immediate Cause:	Limestone roof settled on to the CM
Contributing Factors:	Fireclay band beneath planned seam floor, not highlighted in data package, nil immediate drilling, and impact not incorporated into entry design – weighted load on limestone beam in roof as pillars pressed into clay leading to beam failure and entrapment of CM.

Remedial Action:	Attempted recovery of CM (failed)
Resource Assessment:	*An awareness of an over reliance on standard entry design formulas without detailed assessment of strata and associated properties and allowance for impacts in design should underpin recommendations at the assessment phase .*

Example 4:

Outcome:	Buried CM
Immediate Cause:	Rib failure
Contributing Factors:	The HWM entry design was based on two pass HWM to a height of 8/9 metres at a seam dip of nominally 20 degrees and achieved depth of cover of 200 plus metres. Alternate long/short entries and long entries had single pass to maximum depth (200 plus metres) and double pass to 100 plus metres. Decision made to try triple pass (12 metres high) resulted in pillar failure and highwall failure, CM was left in entry pending site visit by inspectorate, ribs failed in entry and CM was entrapped.
Remedial Action:	Attempted recovery of CM (failed)
Resource Assessment:	*Any decision to alter the agreed geotech/entry design must be undertaken in a processed manner incorporating all technical inputs and should not be made on the basis of "operational experience".*

REGULATORY ENVIRONMENT

Consent to vary current plans:

There are some inherent differences between Regulatory bodies in NSW and QLD and associated processes and attitudes to HWM that need to be understood in any assessment exercise and/or approvals process.

Statutory requirements associated with the technology, whilst incurring opinion and interpretation differences between sites, engineers and Inspectors leading to frustration over inconsistencies and delays, can generally be managed.

The more influential (to project commencement) regulatory problem is that associated with the applicable approvals/consent process. This is particularly problematic in NSW where the concept of a MOP variation (still current in QLD) has been replaced with convoluted requirements to apply to various regulatory entities, each of which has the potential to reopen the project to protestation from organisations focused on the cessation of mining and with extensive media savvy and clout.

> *Therefore, any submission to regulatory authorities for future mining should include a provision around the use of HWM, this simple statement negates the variation process if in the future the operation wished to introduce HWM.*

In QLD and the USA, a process based on modifying current operation plans without reopening public access remains.

THE (MYTHICAL) EXTRA STRIP

Confusion exists at times within the industry as to what definitively constitutes Highwall Mining and direct and inappropriate comparisons are drawn between differing technologies (e.g. Addcar and Augers) and at times decisions are made that actually result in the sterilisation of resource. In addition, examples from past experiences are referenced and applied within a current project context, often resulting in incorrect conclusions.

Oft heard quote; HWM "destroys highwall" is based on a widely held view that by simply waiting there will be a turn in market conditions such that the economic limit of mining will alter sufficiently to allow surface mining to recommence and past decisions to undertake HWM have destroyed such opportunities.

Subject to appropriate assessment of the resource and suitability to HWM, a typical blocked HWM reserve should conservatively be able to achieve an average depth of 320 metres or more. At a conservative recovery basis of 45% this equates to the advancement of the highwall by approximately 144 metres or nominally three additional strips.

Any decision around the introduction of HWM versus waiting for the market needs to be based on a full economic analysis of where the market needs to be to achieve three additional strips versus the cash now.

The possible transition from surface extraction to punch longwalls is an obvious option but the capex requirements for equipment and panel development are not insignificant and there is a probable time delay in sourcing and establishing the longwall operations etc. One consideration is to lengthen the barrier between the surface and the take-off road and introduce HWM, obviously driven by resource and boundary conditions but if achievable, a barrier of 200/300 meters could be successfully HWM mined and early cash flow introduced into the economics of the project.

Of course a myriad of other factors associated with market availability and price, forex rates, anticipated time and confidence in market change occurring, need for sustaining cash, rehabilitation pressures and alternate options need to be considered, but the "watch and wait" position is rarely satisfactory as a stand-alone outcome.

CONCLUSIONS

HWM continues to be realistic option to achieve the optimum utilisation of available resources, the assessment (feasibility) phase of any project should incorporate HWM into the analysis and leave open the possibility for the future.

Existing projects need to collate as much data as possible to confirm methodology, resource and production targets and alignment with the capability of the technology.

DISCLAIMER AND ACKNOWLEDGMENTS

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